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Chapter

Effects of Grazing Intensity on Belowground Carbon and Nitrogen Cycling

Guiyao Zhou, Lingyan Zhou and Xuhui Zhou

Abstract

Livestock grazing activities substantially affect grassland ecosystem functions such as carbon (C) and nitrogen (N) cycles. Although numerous individual and synthesized studies had been conducted, how grazing, especially its intensity, affects belowground C and N cycling in grasslands remains poorly understood. In this chapter, our previous published studies were summarized to elucidate the 19 variables associated with belowground C and N cycling in response to livestock grazing across global grasslands. Overall, grazing significantly decreased belowground C and N pools in grassland ecosystems, with the largest decreases observed in microbial biomass C and N (21.62 and 24.40%, respectively). However, the response magnitude and directions of belowground C- and N-related variables largely depend on grazing intensities. Specifically, light grazing promoted soil C and N sequestration, whereas moderate and heavy grazing significantly accelerated C and N losses. This study highlights the importance of grazing intensity for belowground C and N cycling, which urges scientists to incorporate it into regional and global models for predicting human disturbance on global grasslands and assessing the climate-biosphere feedbacks accurately.

Keywords: carbon sequestration, CO_2 emission, heavy grazing, mineralization, soil microbial biomass

1. Introduction

The global grasslands cover 59 million km^2 (nearly 40%) of the terrestrial land [1] and store 10–30% of the global soil organic carbon (SOC, [2]). Currently, the majority of grasslands around the world are suffering from overgrazing [3], which may impose profound effects on ecosystem services and functions by altering the biogeochemical cycle, especially on carbon (C) and nitrogen (N) cycles [4, 5]. The altered C and N cycles may lead to a positive or negative climate-biosphere feedback, which in turn amplify or diminish their net effects on biodiversity and stability of grasslands. Therefore, understanding the C and N cycles in response to grazing is crucial for us to better predict future global C balance and enhance the sustainable management of grasslands [6].

Over past 30 years, numerous studies have been conducted to explore the C and N cycles of aboveground processes in response to grazing in grassland ecosystems, which have substantially improved our understanding of the grazing effects and the potential mechanisms [3, 7, 8]. For example, intermediate grazing may increase more aboveground biomass C than light and heavy grazing because of higher plant diversity [9, 10]. However, due to the spatial heterogeneity and methodological difficulties, the effects of grazing on belowground process remain poorly understood especially at global scale. Although plenty of studies have investigated the effects of grazing on belowground C and N cycles, however, diverse results were reported with increase [11], decrease [12] and no changes [13].

Recent studies have found that the contradictory effects of grazing on belowground C and N cycles may be associated with grazing intensities, climatic conditions, and vegetation types [8, 14]. Compared with other factors, grazing intensity may be the key driver regulating belowground C and N cycles because it significantly alters soil microenvironment, soil nutrients availability, plant community structure, and soil microbial diversity [15, 16]. However, current understanding of the effects of grazing intensity on belowground C and N cycles were also contradictory. For example, Schuman et al. [17] found that neither light nor heavy grazing could significantly change total plant biomass and soil C and N pools. By contrast, response of soil C and N pools would decrease with increased grazing intensity in water-limited grassland [18]. These knowledge gaps may trigger great challenges for us to precisely assess the climate-biosphere feedbacks in the future [14]. Therefore, this chapter mainly focused on the general response patterns of belowground C and N cycles to different grazing intensities and explored its underlying mechanisms at the global scale.

2. Belowground C and N pools and fluxes

Grazing intensity significantly affects the belowground C and N pools and fluxes, because grazing intensity alters plant community structure, soil microenvironment, and soil microbial diversity and activity [15, 19, 20]. A meta-analysis of 115 published studies demonstrated that grazing significantly influenced belowground C and N cycles at the global scale (**Figure 1**). Moreover, grazing intensity usually influenced the response magnitude (even direction) of the majority of the assessed belowground C and N pools and fluxes. For example, light grazing increased soil carbon pool (SCP) and soil nitrogen pool (SNP) by 0.78 and 3.24%, respectively ($P < 0.01$, **Figure 2**). However, moderate and heavy grazing significantly decreased SCP by 3.45 and 9.92%, and SNP by 8.41 and 13.04%, respectively, resulting in a diminishing effects on soil C:N ratio from light to heavy grazing (SCN, **Figure 2**). Light grazing may increase the above and belowground biomass, which could stimulate more photosynthetically fixed C allocated to roots and then leading the increase of root exudates and root biomass [12, 14, 21]. Grazing-induced increase in root exudates may further enhance soil C accumulation as well N inputs into soils [22]. Meanwhile, light grazing can also stimulate soil respiration due to the increased root biomass and soil C accumulation [10, 23, 24]. However, both moderate and heavy grazing could markedly decrease SCP and SNP (**Figures 2** and **3**), which was consistent with some previous studies [25–27]. The decreased SCP and SNP may result from that fact that grazing can decrease litter biomass, root C pool and microbial biomass and then lower C inputs to soils (**Figures 3** and **4** [17, 28, 29]).

The altered C and N pools induced by grazing intensity also caused the difference of belowground C and N fluxes. On average, soil respiration (Rs) increased by 11.53% under light intensity, whereas moderate and heavy intensities decreased it by 12.7 and 32.6%, respectively. The weighted response ratios of soil net N mineralization (SNNM) decreased by 48.87–10.85% from light to heavy grazing intensities. However, light grazing did not affect the response ratios of soil net N nitrification (SNNN), but moderate and heavy grazing intensities significantly increased [RR_{++} (SNNN)] by 13.43 and 103.06%, respectively. The differential responses of belowground fluxes may be caused by the following

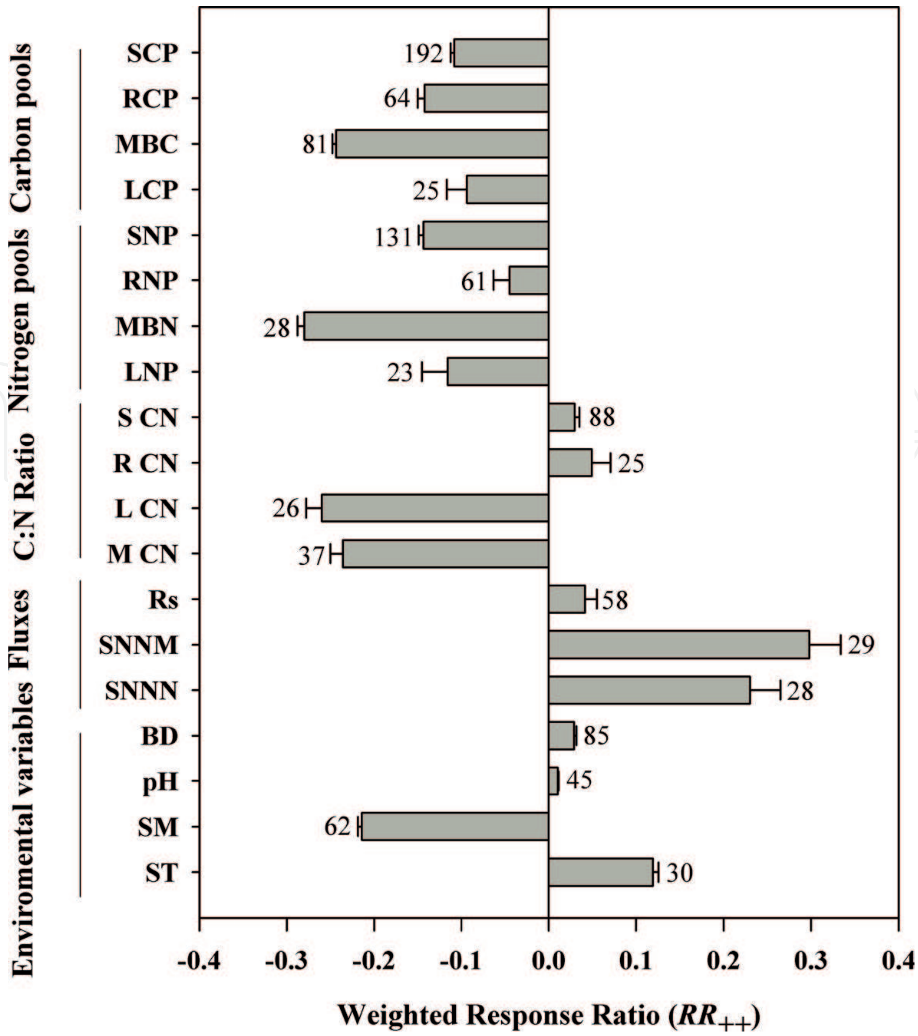

Figure 1.
Weighted response ratio (RR_{++}) of 19 variables related to carbon and nitrogen cycling in response to grazing. Bars represent 95% confidence intervals. The vertical line was drawn at RR_{++} = 0. Numbers for each bar indicate the sample size. SCP, soil carbon pool; RCP, root carbon pool; MBC, microbial biomass carbon; LCP, litter carbon pool; SNP, soil nitrogen pool; RNP, root nitrogen pools; MBN, microbial biomass nitrogen; LNP, litter nitrogen pool; SCN, soil C:N ratio; MCN, microbial biomass C:N ratio; RCN, root C:N ratio; Rs, soil respiration; SNNM, soil net mineralization; SNNN, soil net N nitrification; BD, bulk density; SM, soil moisture; ST, soil temperature.

mechanisms: (1) difference in carbon allocation to roots. The increased C allocation induced by light grazing to root would stimulate the biomass accumulations, which could further increase root activity and C inputs to soil. Moderate and heavy grazing probably also depressed soil infiltrability and nutrient availability, inhibiting plant biomass accumulation and microbial activity [30]; (2) Micro-environment regulations. Light grazing would increase soil moisture because that the enhanced ground covers and decreased soil compaction [21, 31]. Light grazing induced increase in soil temperature and moisture may stimulate plant growth and microbial activities, which would further increase soil respiration [30]. The faster soil evaporation with poor ground cover under moderate and heavy grazing would lower soil moisture, which might also further explain the decreased soil respiration [20, 30, 31].

3. Interaction with biotic and abiotic factors

Grazing effects on belowground carbon and nitrogen cycling were also regulated by biotic (e.g., livestock type) and abiotic factors (e.g., MAP, MAT and soil

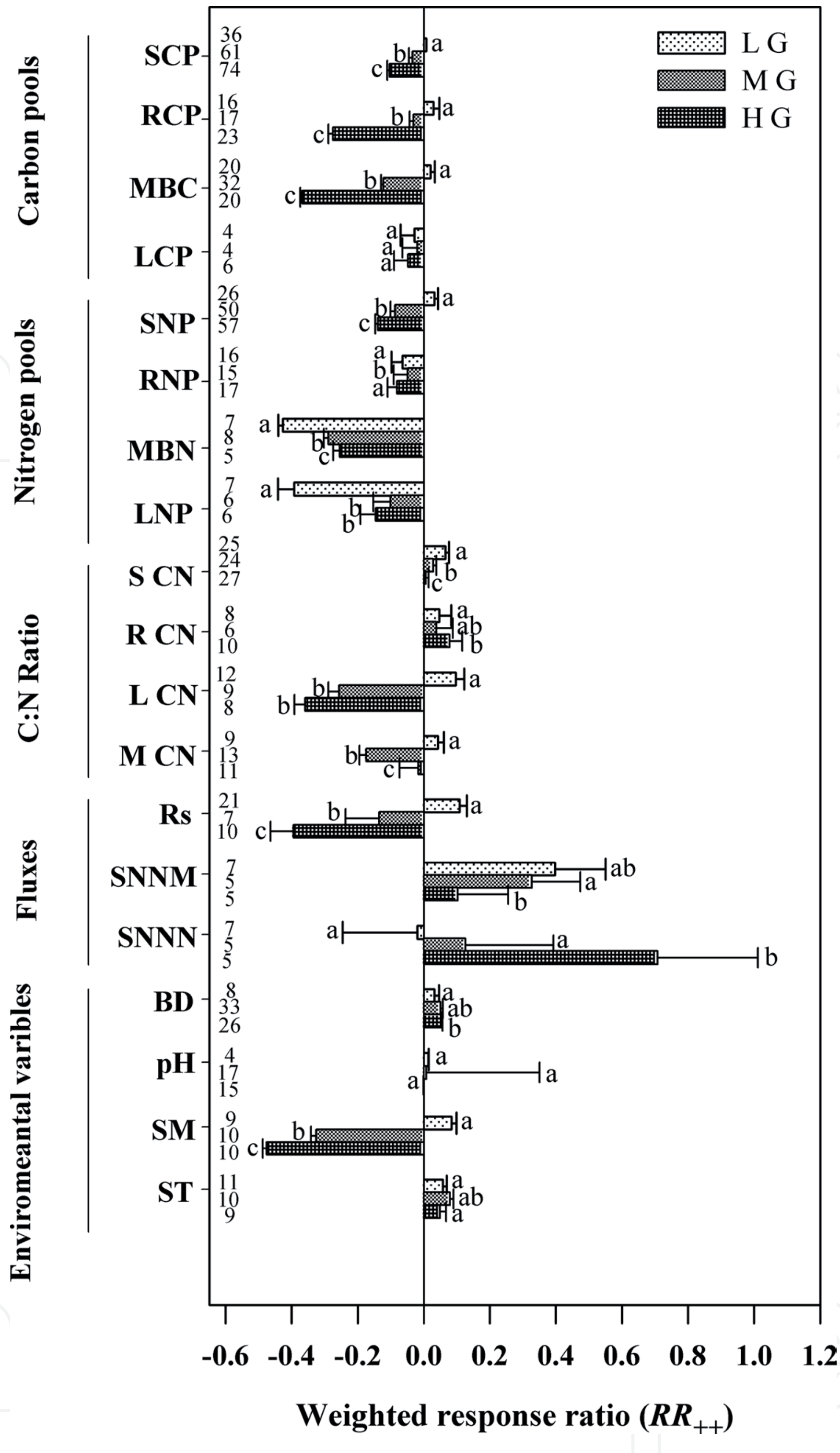

Figure 2.
Weighted response ratio (RR_{++}) of 19 variables related to carbon and nitrogen cycles in response to different grazing intensity. Bars represent RR_{++} ± 95% confidence intervals. The vertical line was drawn at RR_{++} = 0. Numbers for each bar indicate the sample size. Symbols a, b *and* c *represents the significant differences among three grazing intensities for the responses of selected variables to grazing. SCP, soil carbon pools; RCP, root carbon pools; MBC, microbial biomass carbon; LCP, litter carbon pools; SNP, soil nitrogen pools; MBN, microbial biomass nitrogen; LNP, litter nitrogen pools; RNP, root nitrogen pools; SCN, soil C:N ratio; MCN, microbial biomass C:N ratio; RCN, root C:N ratio; Rs, soil respiration; SNNM, soil net mineralization; SNNN, soil net N nitrification; BD, bulk density; SM, soil moisture; ST, soil temperature; LG, light grazing; MG, moderate grazing; HG, heavy grazing.*

depth). It has been showed that root carbon pool (RCP), soil nitrogen pool (SNP) and root nitrogen pool (RNP) decreased more in semi-humid/humid regions (MAP ≥ 400 mm) than in arid/semi-arid regions under grazing (MAP < 400 mm, **Figures 5** and **6**). However, microbial biomass carbon (MBC) and litter carbon pool

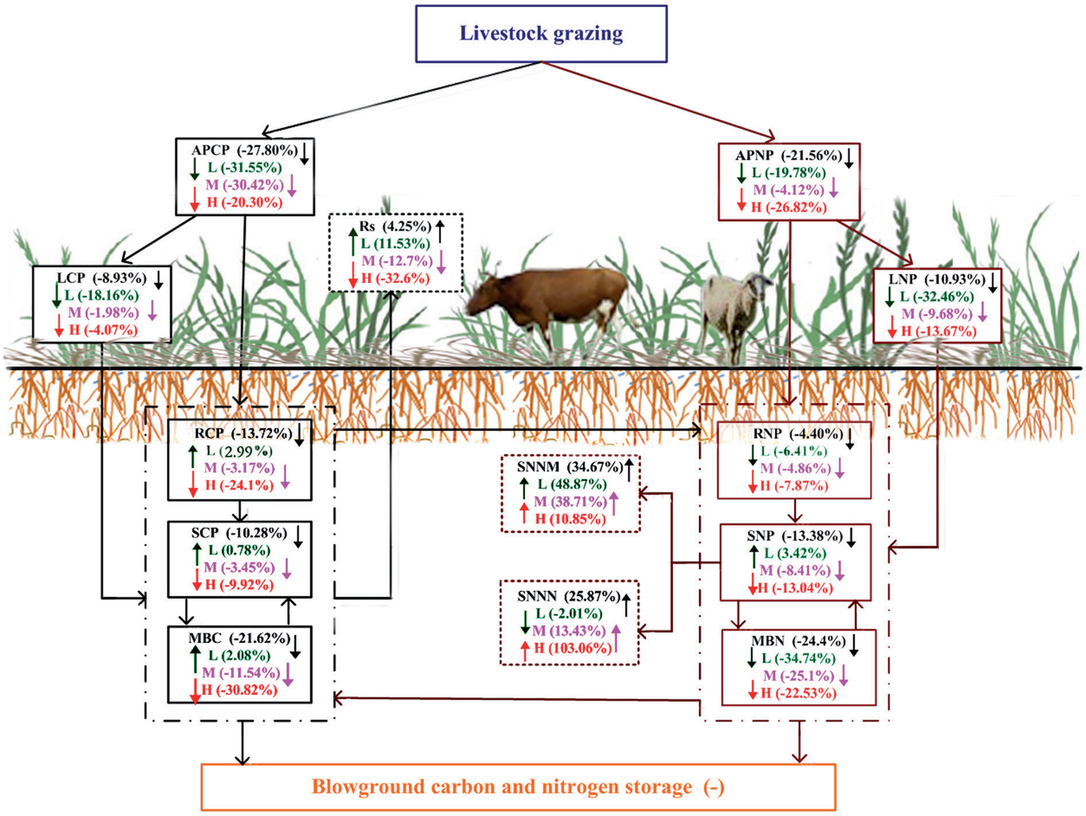

Figure 3.
Potential mechanisms of belowground C and N processes in response to livestock grazing. The numbers refer to percentage change (e^{RR++} − 1) × 100% of belowground C and N variables in response to grazing. SCP, soil carbon pools; RCP, root carbon pools; MBC, microbial carbon; LCP, litter carbon pools; SNP, soil nitrogen pools; MBN, microbial nitrogen; LNP, litter nitrogen pools; RNP, root nitrogen pools; APCP, aboveground plant carbon pools; APNP, aboveground plant nitrogen pools. APCP and APNP data was provided in supporting information. L, light grazing intensity presented with green color; M, moderate grazing intensity presented with purplish color; H, heavy grazing intensity presented with red color. ↑, positive response to livestock grazing; ↓, negative response to livestock grazing.

(LCP) exhibited larger negative response to grazing in arid/semi-arid regions than in semi-humid/humid regions. These differences may result from the interactions with precipitation. MAP exhibited a significant positive correlation with the response of SCP ($P < 0.05$), but it was not correlated with response of SNP to grazing (**Figure 7**). Since faster root turnover in wetter regions, grazing lead a larger decrease in RCP in semi-humid/humid than arid/semi-arid climate regions [32]. Due to the close relationship between LCP and MBC, RR(MBC) exhibited a similar response trend with LCP (**Figure 4**, [33]). Grazing significantly decreased MBC and LCP in arid/semi-arid climate, where lower productivity was more responsive to grazing than those in semi-humid/humid conditions. In addition, grazing may substantially reduce MBC in arid/semi-arid climate due to the larger decrease of litter inputs [34, 35]. Furthermore, *Rs* in semi-humid/humid regions increased more than that in arid/semi-arid regions, which might be associated with the existing high net ecosystem productivity [36] and high microbial activity [37] in the wetter regions than those in drier ones. Our study also further found that MAP exhibited a positive correlation with *RR* (*SCP*) (**Figure 7**, **Table 1**), which was consistent with Mcsherry and Ritchie [14] and Hu et al. [38]. Because that plant productivity and microbial activity in wetter areas are usually greater than those in drier regions, the actual responses of SCP to grazing may have been masked, causing weak positive correlation between MAP and SCP [39, 40].

Temperature is another important factor influencing grazing effects on belowground C and N cycles. Our results found that MAT exhibited negative correlations with RR(SCP) and RR(SNP) at global scale (**Figure 7**; **Table 1**). These changes

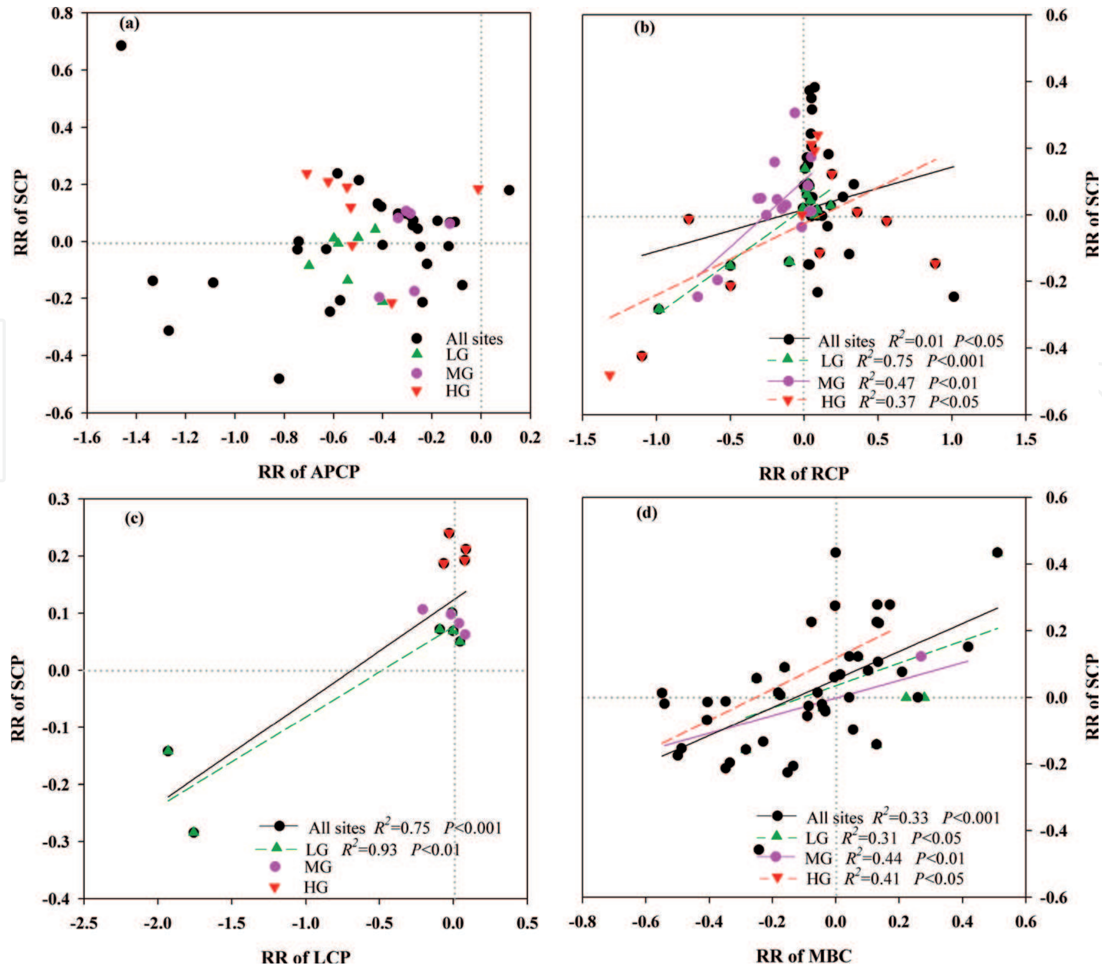

Figure 4.
Relationships of response ratios (RR) of soil carbon pools (SCP) with aboveground carbon pools (APCP, a), root carbon pools (RCP, b), litter carbon pools (LCP, c) and microbial biomass carbon pools (MBC, d). All sites represented the data for all intensities and some with no intensity information—black closed circles; LG, light grazing intensity—green closed triangles; MG, moderate grazing intensity—purple closed circles; HG, heavy grazing intensity—red closed triangles.

may result from the fact that grasslands with higher MAT in tropical and temperate regions usually have greater microbial activity than those in boreal regions with the lower MAT [32]. The higher microbial activity in high-MAT regions can usually accelerate decomposition of soil organic matter and increase turnover rate, and then decrease SCP and SNP more in those grazed ecosystems, resulting in the negative correlation between MAT and *RR* (*SCP*) or *RR* (*SNP*). On the other hand, soil temperature, water content and their interactions fundamentally determine the temporal dynamics of C cycle in grassland ecosystem, especially for soil respiration [41].

Different livestock types and soil depths showed different magnitudes of changes (even direction) for many of the considered variables (**Figure 6**). Using meta-analysis, we found that sheep grazing induced the changes in SCP, SNP, RCP and RNP exhibited a greater decrease than those by cattle. These changes may result from the difference in foraging selectivity by different livestock, causing the variation of plant species composition and community structure, which further induced the difference of C and N inputs/outputs [29]. We also found that the response of MBC at the depth of <15 cm to grazing was positive, while this at depth of >15 cm was negative. Grazing may induced the spatial variations of root distribution and sensitivity to environment within plant–soil system at different depths, which thus causing the different response of belowground C and N cycles to grazing activity [17, 42, 43].

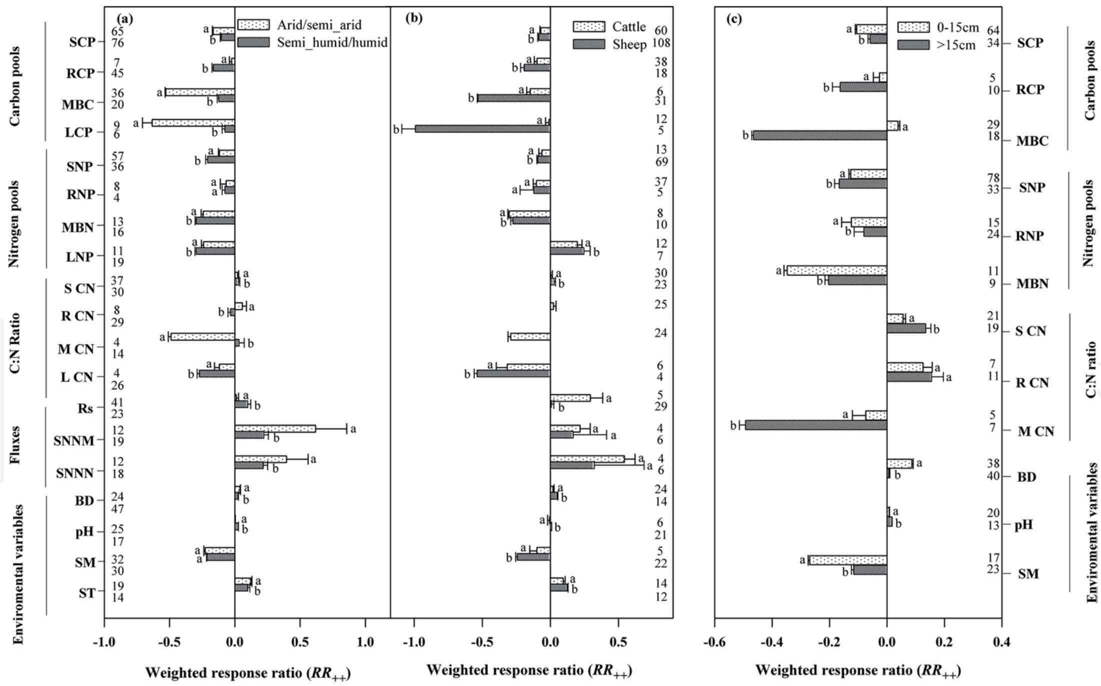

Figure 5.
*Weighted response ratio (RR_{++}) of 19 variables related to carbon and nitrogen cycles in response to arid/semi-arid-white columns and semi-humid/humid-gray columns (**a**), cattle grazing—white columns and sheep grazing—gray columns (**b**), 0-15 cm - white columns and > 15 cm—gray columns (c). Bars represent RR_{++} ± 95% confidence intervals. The vertical line was drawn at RR_{++} = 0. Numbers for each bar indicate the sample size. Symbols* a *and* b *represent the significant differences among two categories (panel a, arid/semi-arid vs. semi-humid/humid climate; panel b, cattle vs. sheep grazing; panel c, soil depth of 0–15 cm vs. >15 cm) for the responses of selected variables to grazing. SCP, soil carbon pools; RCP, root carbon pools; MBC, microbial carbon; LCP, litter carbon pools; SNP, soil nitrogen pools; MBN, microbial nitrogen; LNP, litter nitrogen pools; RNP, root nitrogen pools; SCN, soil C:N ratio; MCN, microbial C:N ratio; RCN, root C:N ratio; Rs, soil respiration; SNNM, soil net mineralization; SNNN, soil net N nitrification; BD, bulk density; SM, soil moisture; ST, soil temperature.*

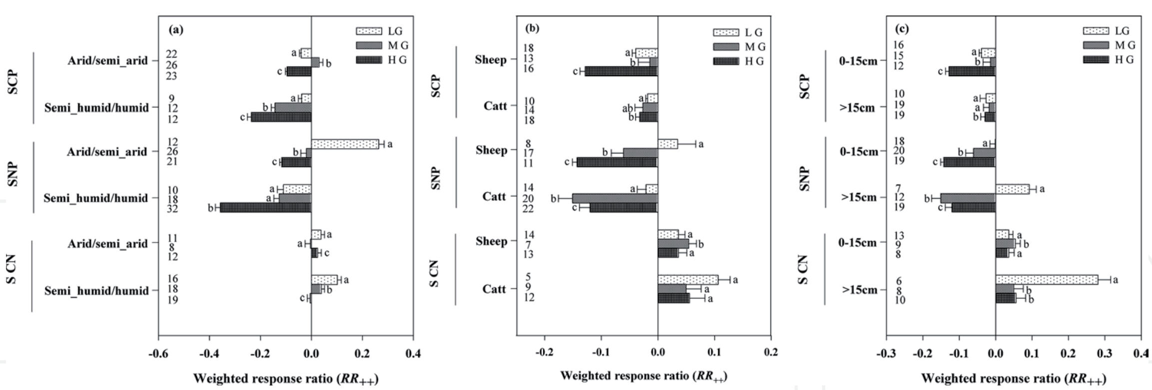

Figure 6.
Weighted response ratio (RR_{++}) of soil carbon pools (SCP), soil nitrogen pools (SNP), and soil C:N ratio (SCN) in different grazing intensities with respect to climate type (a), livestock type (b) and soil depth (c). Bars represent RR_{++} ± 95% confidence intervals. The vertical line was drawn at RR_{++} = 0. Number values for each bar indicate the sample size. Symbols a, b *and* c *represents the significant differences among three grazing intensities for the responses of selected variables to grazing.*

Livestock type, climate type, and soil depth also affected the overall magnitude and even direction of the weighted response ratios of SCP, SNP as well as SCN under different grazing intensities (**Figure 6**). The meta-analysis shows that both SCP and SNP in semi-humid/humid regions decreased with increasing intensity, whereas moderate and light grazing exhibited positive effects on SCP and SNP in arid/semi-arid regions. Decreased SCP was highest under heavy grazing, followed by light and moderate grazing, irrespective of cattle or sheep grazing. Light grazing

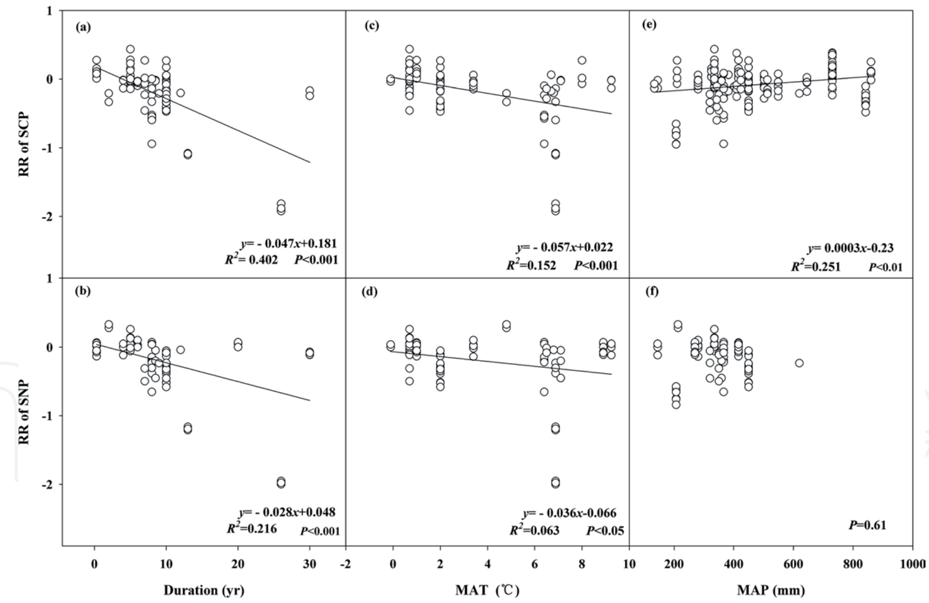

Figure 7.
Relationships of grazing duration (a, b), mean annual temperature (MAT, c, d), and mean annual precipitation (MAP, e, f) with response ratios (RR) of soil carbon pools (SCP, a, c, e) and soil nitrogen pools (SNP, b, d, f).

exhibited positive effects on SNP at the depth of >15 cm, while both moderate and heavy grazing had the opposite effects on it at the same depth (**Figure 6**). These differences induced by livestock type, climate type and soil depth may results from the complex interaction between grazing intensity with water, temperature and nutrients, but the potential mechanisms was still unknown and need further investigations.

4. Implication for grassland management

Overgrazing is a primary contributor to grassland degradation and desertification, which may significantly affect ecosystems functions and then lead to positive or negative climate-biosphere feedbacks [8, 25]. The regional and global studies showed that grazing intensity is a very important role in regulating belowground C and N pools and fluxes, which may offer some suggestions for future grassland management and model development. First, the effects of grazing intensity on C and N cycles may be regulated by environmental conditions (e.g., nitrogen and water availability; [8]). However, how the interactions of grazing with global change factors (e.g., warming, nitrogen addition, elevated CO_2, increased precipitation and drought) is influenced by grazing intensity remain unknown [44, 45]. These knowledge gaps may impede us to fully understand how grazing affects C and N cycles of grasslands at global scale.

Second, current global synthesized studies showed that most of current grazing studies were distributed in temperate climates, such as eastern Asia and North America, and only few studies were conducted in cold and tropical regions [5, 6]. Thus, more studies from other regions (e.g., Africa and Australia) should be conducted in order to develop a more comprehensive understanding of how grazing intensity influence C and N cycling of global grasslands. Another problem is the experimental duration. Most of current grazing experiments were less than 10 years, due to the high costs and long time scale. The grazing effects on C and N cycle may vary with time [5]. Hence, there is a need to conduct studies over one decade to better understand the effects of grazing on belowground C and N cycling.

P values of the correlations	**Pearson correlation coefficients**							
	***RR*(SCP)**	***RR*(SNP)**	***RR*(BD)**	***RR*(SM)**	**Latitude**	**MAP**	**MAT**	**Duration**
RR(SCP)		0.911**	−0.529**	0.135	−0.228*	0.201*	−0.474**	−0.634**
RR(SNP)	<0.001		−0.527**	0.080	−0.029	−0.055	−0.359**	−0.465**
RR(BD)	<0.001	<0.001		−0.742**	−0.367**	0.364**	−0.242	0.415**
RR(SM)	0.493	0.702	<0.001		0.546**	−0.366*	0.234	−0.267
Latitude	0.021	0.783	0.003	<0.001		−0.455**	0.396**	0.538**
MAP	0.045	0.610	0.005	0.033	<0.001		−0.656**	−0.061
MAT	<0.001	<0.001	0.052	0.190	<0.001	<0.001		0.359**
Duration	<0.001	<0.001	0.002	0.170	<0.001	0.571	<0.001	

The environmental/forcing variables are latitude, longitude, Mean annual precipitation (MAP), mean annual temperature (MAT), RRBD (Bulk Density), RRSM (Soil Moisture) and grazing time (Duration). The values on up-right side of the diagonal are Pearson correlation coefficients. The values on low-left side of the diagonal are P values to indicate statistical significance of the correlation coefficients.
Note: $^{*}P < 0.05$; $^{**}P < 0.01$; $^{***}P < 0.001$.

Table 1.
Correlation analysis of environmental variables with each other and with response ratio of SCP [RR(SCP)] and SNP [RR(SNP)] of surface soil (<15 cm).

Third, grazing intensity (light, moderate, and heavy grazing) significantly affects belowground C and N cycling in grassland ecosystems. Meanwhile, different combinations of grazing and global change factors (e.g., warming, nitrogen addition) also have disparate effects on C and N cycle of grasslands [8]. However, current land-surface models did not usually differentiate the effects of grazing intensities as well as their combinations with global change factors, which may trigger great challenges for us to predict the C-climate feedbacks in the Anthropocene. Therefore, future land-surface models may need thus to fully consider these processes in order to develop more precise process-based mechanism for forecasting the feedback of grassland ecosystems to climate change.

Fourth, environmental factors (both MAP and MAT) may be crucial in evaluating the response of belowground C and N cycling to different driving factors, as the effects of grazing, global change factors, and their combinations on belowground C and N cycling may change with MAT and MAP transects [6, 14]. The global study also demonstrated that response ratios of soil carbon content and soil nitrogen content to grazing in warmer biomes was clearly higher than those in the low range (**Figure 7**). These results demonstrated the importance of decreasing grazing frequency and intensity in warmer regions than colder ones, which may help to increase soil C sequestration in ecological fragile areas.

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Conflict of interest

All authors declare no conflict of Interests.

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References

[1] Hufkens K, Keenan TF, Flanagan LB, Scott RL, Bernacchi CJ, Joo E, et al. Productivity of North American grasslands is increased under future climate scenarios despite rising aridity. Nature Climate Change. 2016;**6**:710-716

[2] Follett RF, Reed DA. Soil carbon sequestration in grazing lands: Societal benefits and policy implications. Rangeland Ecology and Management. 2010;**63**:4-15

[3] Salvati L, Carlucci M. Towards sustainability in agro-forest systems? Grazing intensity, soil degradation and the socioeconomic profile of rural communities in Italy. Ecological Economics. 2015;**112**:1-13

[4] Bai YF, Wu JG, Clark CM, Pan QM, Zhang LX, Chen SP, et al. Grazing alters ecosystem functioning and C:N:P stoichiometry of grasslands along a regional precipitation gradient. Journal of Applied Ecology. 2012;**49**:1204-1215

[5] Zhou GY, Zhou XH, He YH, Shao JJ, Hu ZH, Liu RQ, et al. Grazing intensity significantly affects belowground carbon and nitrogen cycling in grassland ecosystems: A meta-analysis. Global Change Biology. 2017;**23**:1167-1179

[6] Zhou GY, Luo Q, Chen YJ, Hu JQ, He M, Gao J, et al. Interactive effects of grazing and global change factors on soil and ecosystem respiration in grassland ecosystems: A global synthesis. Journal of Applied Ecology. 2019;**56**:2007-2019

[7] Yan L, Zhou GS, Zhang F. Effects of different grazing intensities on grassland production in China: A meta-analysis. PLoS One. 2013;**8**:e81466

[8] Zhou GY, Luo Q, Chen Y, He M, Zhou LY, Frank D, et al. Effects of livestock grazing on grassland carbon storage and release override impacts associated with global climate change. Global Change Biology. 2019a;**25**:1119-1132

[9] Connell JH. Diversity in tropical rain forests and coral reefs. Science. 1978;**199**:1302-1310

[10] Gong JR, Wang YH, Liu M, Huang YM, Yan X, Zhang ZY, et al. Effects of land use on soil respiration in the temperate steppe of Inner Mongolia, China. Soil and Tillage Research. 2014;**144**:20-31

[11] Knops JMH, Tilman D. Dynamics of soil nitrogen and carbon accumulation for 61 years after agricultural abandonment. Ecology. 2000;**81**:88-98

[12] Liu N, Kan HM, Yang GW, Zhang YJ. Changes in plant, soil, and microbes in a typical steppe from simulated grazing: Explaining potential change in soil C. Ecological Monographs. 2015;**85**:269-286

[13] Bagchi S, Ritchie ME. Introduced grazers can restrict potential soil carbon sequestration through impacts on plant community composition. Ecology Letters. 2010;**13**:959-968

[14] Mcsherry ME, Ritchie ME. Effects of grazing on grassland soil carbon: A global review. Global Change Biology. 2013;**19**:1347-1357

[15] McNaughton S, Ruess R, Seagle S. Large mammals and process dynamics in African ecosystems. Bioscience. 1988;**38**:794-800

[16] Zhou XQ, Wang JZ, Hao YB, Wang YF. Intermediate grazing intensities by sheep increase soil bacterial diversities in an inner Mongolian steppe. Biology and Fertility of Soils. 2010;**46**:817-824

[17] Schuman GE, Reeder JD, Manley JT, Hart RH, Manley WA. Impact of grazing

management on the carbon and nitrogen balance of a mixed-grass rangeland. Ecological Applications. 1999;**9**:65-71

[18] Liu N, Zhang YJ, Chang SJ, Kan HM, Lin LJ. Impact of grazing on soil carbon and microbial biomass in typical steppe and desert steppe of Inner Mongolia. PLoS One. 2013;**7**:e36434

[19] Manley J, Schuman G, Reeder JD, Hart RH. Rangeland soil carbon and nitrogen responses to grazing. Journal of Soil and Conservation. 1995;**50**:294-298

[20] Stavi I, Ungar ED, Lavee H, Lavee H, Sarah P. Grazing-induced spatial variability of soil bulk density and content of moisture, organic carbon and calcium carbonate in a semi-arid rangeland. Catena. 2008;**75**:288-296

[21] Zhang T, Zhang YJ, Xu MJ, Zhu JT, Wimberly MC, Yu GR, et al. Light-intensity grazing improves alpine meadow productivity and adaption to climate change on the Tibetan plateau. Scientific Reports. 2015;**5**:15949

[22] Derner J, Briske D, Boutton T. Does grazing mediate soil carbon and nitrogen accumulation beneath C_4, perennial grasses along an environmental gradient? Plant and Soil. 1997;**191**:147-156

[23] Baker JM, Ochsner TE, Venterea RT, Griffis TJ. Tillage and soil carbon sequestration—What do we really know? Agriculture, Ecosystems and Environment. 2007;**118**:1-5

[24] Reicosky DC. Tillage-induced CO_2 emission from soil. Nutrient Cycling in Agroecosystems. 1997;**49**:273-285

[25] He NP, Zhang YH, Yu Q, Chen SP, Pan QM, Zhang GM, et al. Grazing intensity impacts soil carbon and nitrogen storage of continental steppe. Ecosphere. 2011;**2**:304-316

[26] Parton WJ, Schimel DS, Cole CV, Ojima DS. Analysis of factors controlling soil organic matter levels in Great Plains grasslands. Soil Science Society of America Journal. 1987;**51**:1173-1179

[27] Wu HH, Wiesmeier M, Yu Q, Steffens M, Han XG, Kögel-Knabner I. Labile organic C and N mineralization of soil aggregate size classes in semiarid grasslands as affected by grazing management. Biology and Fertility of Soils. 2012;**48**:305-313

[28] Detling J, Dyer M, Winn D. Net photosynthesis, root respiration, and regrowth of *Bouteloua gracilis* following simulated grazing. Oecologia. 1979;**41**:127-134

[29] Knops JMH, Bradley KL, Wedin DA. Mechanisms of plant species impacts on ecosystem nitrogen cycling. Ecology Letters. 2002;**5**:454-466

[30] Savadogo P, Sawadogo L, Tiveau D. Effects of grazing intensity and prescribed fire on soil physical and hydrological properties and pasture yield in the savanna woodlands of Burkina Faso. Agriculture Ecosystems and Environment. 2007;**118**:80-92

[31] Thomey ML, Collins SL, Vargas R, Johnson JE, Brown RF, Natvig DO, et al. Effect of precipitation variability on net primary production and soil respiration in a Chihuahuan Desert grassland. Global Change Biology. 2011;**17**:1505-1515

[32] Chapin IIFS, Matson PA, Mooney HA. Principles of Terrestrial Ecosystem Ecology. New York, NY, USA: Springer; 2002

[33] Su YZ, Li YL, Cui HY, Zhao WZ. Influences of continuous grazing and livestock exclusion on soil properties in a degraded sandy grassland, Inner Mongolia, northern China. Catena. 2005;**59**:267-278

[34] Osem Y, Perevolotsky A, Kigel J. Site productivity and plant size explain the response of annual species to grazing exclusion in a Mediterranean semi-arid rangeland. Journal of Ecology. 2004;**92**:297-309

[35] Shi XM, Li XG, Li CT, Zhao Y, Shang ZH, Ma QF. Grazing exclusion decreases soil organic C storage at an alpine grassland of the Qinghai–Tibetan plateau. Ecological Engineering. 2013;**57**:183-187

[36] Xia JY, Niu SL, Wan SQ. Response of ecosystem carbon exchange to warming and nitrogen addition during two hydrologically contrasting growing seasons in a temperate steppe. Global Change Biology. 2009;**15**:1544-1556

[37] Zhou XH, Talley M, Luo YQ. Biomass, litter, and soil respiration along a precipitation gradient in southern Great Plains, USA. Ecosystems. 2009;**12**:1369-1380

[38] Hu ZM, Li SG, Guo Q, Niu SL, He NP, Li LH, et al. A synthesis of the effect of grazing exclusion on carbon dynamics in grasslands in China. Global Change Biology. 2016;**22**:1385-1393

[39] Luyssaert S, Inglima I, Jung M. CO_2 balance of boreal, temperate, and tropical forests derived from a global database. Global Change Biology. 2007;**13**:2509-2537

[40] Williams M, Eugster W, Rastetter EB, Mcfadden JP, Chapin FS III. The controls on net ecosystem productivity along an Arctic transect: A model comparison with flux measurements. Global Change Biology. 2000;**6**:116-126

[41] Wang CK, Yang JY, Zhang QZ. Soil respiration in six temperate forests in China. Global Change Biology. 2006;**12**:2103-2114

[42] Holland EA, Detling JK. Plant response to herbivory and belowground nitrogen cycling. Ecology. 1990;**71**:1040-1049

[43] Li CL, Hao XY, Zhao ML, Han GD, Willms WD. Influence of historic sheep grazing on vegetation and soil properties of a desert steppe in Inner Mongolia. Agriculture Ecosystems and Environment. 2008;**128**:109-116

[44] Lu M, Zhou XH, Luo YQ, Yang YH, Fang CM, Chen JK, et al. Minor stimulation of soil carbon storage by nitrogen addition: A meta-analysis. Agriculture Ecosystems and Environment. 2011;**140**:234-244

[45] Zhou LY, Zhou XH, Zhang BC, Lu M, Luo YQ, Liu LL, et al. Different responses of soil respiration and its components to nitrogen addition among biomes: A meta-analysis. Global Change Biology. 2014;**20**:2332-2343